SAFETY EVALUATION REPORT
DEPARTMENT OF ENERGY
MODEL R-1 BUSS CASK
DOCKET 86-1-9511

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SUMMARY

By application dated April 11, 1986, as revised, the United States Department of Energy (DOE) Albuquerque Operations Office requested a DOE Certificate of Compliance (CoC) for the Model No. R-1 shipping package design. The DOE is the owner of the packaging design.

Based on the statements and representation in the Safety Analysis Report for Packaging (SARP) and the conditions listed below, the EH-321 staff has concluded that the Model No. R-1 BUSS Cask design meets the requirements of DOE Order 5480.3 and 10 CFR Part 71.

REFERENCE

Beneficial Uses Shipping System Cask, BUSS, Safety Analysis Report for Packaging (SARP), Volumes I and II, Report SAND 83-0698 (TTC-0430), Revision 3, February 1990, Sandia National Laboratories, Albuquerque, NM 87185.

DRAWINGS

The packaging is constructed in accordance with Sandia National Laboratories Drawing Numbers S54774, Rev. B, Cask in Cradle, and its attendant drawings plus drawing number S52614, Rev. B, Personnel Barrier-Lower and drawing number S52615, Rev. B, Personnel Barrier-Upper.

The cesium chloride encapsulation as defined by Vitro Drawing Numbers H-2-66760, All Revisions for which Special Form tests have been documented; and H-2-66761, All Revisions for which Special Form tests have been documented.

The strontium fluoride encapsulation as defined by Vitro Drawing Numbers H-2-66759, All Revisions for which Special Form tests have been documented; and H-2-66758, All Revisions for which Special Form tests have been documented.

The general information and drawings presented in the reference were reviewed by the staff and found acceptable. The BUSS cask Model R-1 packaging is adequately described by the Sandia National Laboratories drawings. The drawings provide information pertaining to materials of construction, component dimensions and tolerances, and the location and size of all weld joints. The drawings identify the weld joints to be nondestructively examined, the method to be used, and the code or standard for the examination procedure. The SARP requires welders and welding procedures to be qualified in accordance with AWS D1.1 or the ASME Code Section IX.

1. General

The BUSS Cask contents are Category I quantity as defined in DOE/DP-0049, "Packaging Review Guide for Reviewing Safety Analysis Reports for Packagings." However, there are no welds directly involving containment, criticality or shielding in the cask itself, outside of the Special Form capsule welds, to which ASME Code rules for fabrication would be applied.

The BUSS cask Model R-1 is a Type B packaging for shipping up to highway route controlled quantities of nonfissile, radioactive Special Form ^{90}strontium fluoride and ^{137}cesium chloride, double-wall (Type 316L stainless steel, Hasteloy C and Type 316L stainless steel, Type 316L stainless steel) capsules. The total gross weight of the fully loaded packaging is 32,900 pounds. The cask is shipped exclusive use.

This Safety Evaluation Report (SER) does not directly assess the integrity of these Special Form capsules which were manufactured at the Waste Encapsulation and Storage Facility (WESF) in Richland, WA. In accordance with 49 CFR 173.476, the shipper is responsible to demonstrate that the contents meet the Special Form requirements of 10 CFR 71.75 at the time of shipment.

1.1 Description

The BUSS packaging consists of a cylindrical, forged, Type 304 stainless steel cask body and lid with machined fins in the central section of the body to dissipate heat. Each end of the assembled cylindrical body is covered by a foam-filled impact limiter designed to absorb energy by crushing and to thermally insulate the end of the body. The impact limiters are held to the cask with a notch-filling Type 304 stainless steel tape and a set of turnbuckles strapping the limiters to each other. The assembled body with limiters rests in a shipping cradle that includes a screen-type barrier to prevent operating personnel from touching the warm surface. The ready-to-ship assembly is approximately 7 feet in diameter and about 8 feet long.

The Special Form capsules are carried in a basket unit within the cask main body. A number of baskets are available that will accommodate from four to sixteen capsules. The Type 304 stainless steel baskets are essentially solid cylinders with holes drilled for the capsules, providing a positive physical separation of the capsules and large flow areas to dissipate the heat load.

The cask body is machined from a one-piece forging and the walls and bottom are more than 12 inches thick, as is the lid, ensuring sturdiness and pressure resistance. The cask lid is bolted to the body with twelve A-286 1.5 inch diameter, high strength, corrosion resistant bolts compressing a spacer gasket with dual material seals consisting of a metallic inner seal and an organic compound outer seal. The lid seal can be used for only one shipment and a new seal is installed for each cask loading therefore insuring confinement integrity. Two small ports, about 5 inches in diameter, one near each end of the cask body, allow draining after underwater operations. In addition, the ports are used for flush-and-backfill operations to purge the cavity volume and provide an internal helium atmosphere. The helium provides beneficial heat transfer enhancement, but the inadvertent replacement with air will not jeopardize Special Form integrity if the transport period does not exceed 30 days. The ports are sealed with smaller versions of the spacer/dual seal system used on the cask lid. As with the lid seal, these port seals are used only once.

Loading and/or unloading the basket from the BUSS cask may be performed in either a dry cell or a pool. Numerous design features such as the dual ports noted above are available to insure proper and safe operation. To insure correct seal installation during remote handling operations, the seals are bolted to the underside of the closure lids before the lids are fitted onto the cask, thus insuring that uniform pressure and proper positioning is achieved when the lids are mated to the cask. In addition, the double-seal feature of each seal assembly allows for proof-of-seal checking of the between-seal volume.

1.2 Contents and Fissile Class

The cask carries Special Form capsules containing up to 8.5 x 10^5 Curies of ^{90}Strontium fluoride or ^{137}Cesium chloride. These materials are not fissile so no fissile class is assigned.

2. Structural

2.1 Structural Design

2.1.1 General Considerations

The BUSS SARP uses analysis to demonstrate that the regulatory test conditions will result in package behavior that will meet regulatory requirements. There were no full scale tests of the BUSS Cask to confirm the engineering analyses and evaluations presented by the applicant. Scale model tests were performed by the applicant for the development and design of the impact limiters and of the limiter retention systems. These model tests were not referenced in the SARP but were reviewed by the staff as part of the confirmatory analysis process.

2.1.2 Design Criteria

The design criteria are based upon the guidance given in Regulatory Guide (RG) 7.6 and the load combinations are from RG 7.8 except where 10 CFR 71 governs. The allowable stress intensity values and fatigue design stresses are those given in the applicable sections of the ASME Code. For loadings not governed by the ASME Code, the von Mises yield criterion was used. In cases where stresses beyond the elastic limit are calculated, the SARP provides information and safety factors that show the stresses to be acceptable.

2.2 Weights and Center of Gravity

The SARP contains a table listing the weight of each major package component and gives the location of the center of gravity of the package.

2.3 Materials

The Type 304 stainless steel, A-286 bolting, O-ring seal, foam, and other materials selected for use in the packaging construction were found to be adequate to satisfy 10 CFR 71 requirements. Specifically, the applicant has provided references to applicable ASTM standards to show that all materials are identified by authoritative specifications, that brittle fracture will not occur under normal and accident conditions, and that the general corrosion of all materials is negligible.

2.4 General Standards for All Packages

2.4.1 Minimum Package Size

The smallest BUSS cask overall dimension is much larger than the 4 inch minimum limit.

2.4.2 Tamperproof Feature and Positive Closure

The tamper proof seal specified for the tape joint retaining blocks satisfies the requirement.

Positive closure is provided by lid and cover bolts that are not accessible during normal transport.

2.4.3 Chemical and Galvanic Reactions

The materials used in the packaging construction are compatible, and no chemical or galvanic reaction between materials in contact is expected.

2.4.4 Valve or Venting

The BUSS Cask does not have a valve or similar device, and it does not use continuous venting.

2.5 Lifting and Tiedown Standards for All Packages

2.5.1 Lifting Devices

The BUSS Cask is lifted via two lifting lugs, each of which is attached by four 1 inch diameter bolts. A very detailed finite element analysis of the lifting lugs is presented in the SARP. This analysis shows stresses below yield under a load of three times the weight of the cask as required by 10 CFR 71, but assumes that the bolts rigidly clamp the lifting lug base plate to the cask body. This assumption would be acceptable for an analysis intended to determine ultimate strength of the member. However, in a linear elastic analysis, such as reported in the SARP, this assumption will underestimate the stresses by as much as one-half when compared to an analysis that uses a realistic flexibility for the bolts. A confirmatory analysis was performed using beam equations, assuming fixed end beam behavior, and the stresses in the lifting lug under the specified loading conditions were calculated to be two-thirds of the level allowed by 10 CFR 71.45(a). Bolt, bolt insert, and cask body stresses were similarly reviewed and found to be only 20% of yield.

Therefore, the lifting devices meet the 10 CFR 71.45(a) requirement that they not yield when loaded to three times the weight of the package.

In the event of an "excessive load" on a lifting lug, as prescribed by 10 CFR 71.45(a), the lug would experience large, prominent bending deformations at the weld between the two plates of the lifting lug itself. The cask body will continue to fully provide confinement and shielding after experiencing such a load.

Other structural parts of the package that could be used to lift the package are inaccessible during transport since they are covered by the personnel barrier. Moreover, the trunnions, which are intended to function as lifting devices during loading and unloading operations, have a safety factor against yielding that is at least twice the 10 CFR 71.45 requirement of three.

2.5.2 Tiedown Devices

The tiedown system consists of two trunnions bolted to the cask body with two turnbuckles attached to each trunnion through a special yoke. The SARP presents an analysis of the cask and trunnions, subjected to the "10-5-2 times the weight" loading specified in 10 CFR 71. A confirmatory analysis has been performed using the same loadings, with trunnion restraints corresponding to the actual tiedown configuration shown in the SARP. This confirmatory analysis was performed using a cantilever beam model with loading applied at the worst case location consistent with the trunnion and yoke geometry. The maximum stresses calculated were 60 ksi which are well below the 140 ksi yield of the trunnion material. Stresses in other components of the cask, including the trunnion bolts, have also been reviewed and found to be half of yield or less. Therefore, the BUSS Cask meets the 10 CFR 71.45(b)(1) requirement that, under the loadings specified, stresses do not exceed yield.

The turnbuckles will fail when subjected to extreme tiedown loads that generate stresses which are less than yield in any component of the cask. The failure mode meets the 10 CFR 71.45(b)(3) requirement that the failure of the tie downs under extreme load not allow the confinement or shielding of the packaging to be compromised.

2.6 Normal Conditions of Transport

2.6.1 Heat and Cold Conditions

Heat and cold conditions do not impose severe combined stresses on the BUSS cask because Type 304 stainless steel is used throughout. Stresses due to differential thermal expansion are minimal and the stainless steel material maintains acceptable resistance to brittle fracture at operating temperatures down to -40^{o}F.

As reported in the SARP, the normal heat and cold conditions of transport in 10 CFR 71.71(c)(1 and 2) impose stresses that are less than 25% of yield except as noted below. The maximum von Mises stress during normal thermal conditions of transport develops with maximum internal heat generation and minimum external temperatures. Under these conditions, the analyses in the SARP show a local area, the inside corner of the cask cavity, which experiences stresses above yield as calculated by linear elastic analysis. At this point, local compressive stress exceeding yield exists to a depth of at most 5% of the wall thickness. According to ASME classification, this stress is both peak and secondary with either condition allowing a high stress under the ASME Code. The staff determined that the stress will not reach yield because the cask material is sufficiently work hardened to make the actual yield strength higher, and, if yield were reached, it would only occur on the first loading cycle since residual stress would prevent recurrence.

The results presented in the SARP are based on two essentially independent analyses, the first using the commercially available finite element analysis code "ABAQUS" and the second using a Sandia National Laboratory code identified as "JAC". The results are comparable, except that the first analysis did not show the high inside corner stresses noted previously. A confirmatory thermal stress analysis was performed to verify the results presented in the SARP. The temperature distribution that was calculated by the confirmatory thermal analysis, where temperature gradients were about two times those used in the SARP thermal stress analysis, was used in the confirmatory stress analysis. The confirmatory stress analysis was carried out using the ALGOR SUPERSAP computer code. The stresses were found to be less than two times those reported in the SARP and are judged to be acceptable because their levels are within the allowable stress specified by ASME for thermal stresses.

The shear forces across the cask lid bolted closure predicted by the confirmatory analysis are several times greater than those reported in the SARP. Specifically, the SARP analysis indicates that unrestrained relative radial movement between the lid and the cask is so limited that the available bolt forces will prevent movement. Confirmatory analysis indicates that an unrestrained relative radial movement of 10 mils can be expected during initial heatup to the steady state temperature distribution while the bolting provided can restrain only about 1 mil before sliding motion will initiate. Stresses on the bolts remain in the elastic range so breaking or permanent deformation of the bolts is not a concern. Test results, which were furnished by the seal manufacturer, Helicoflex, in response to inquiry by the staff, indicate that several cycles of relative radial movement up to 20 mils in magnitude can be accommodated without helium leakage. Based on these data, the relative radial movement of one-half of a cycle of 10 mils magnitude as predicted by the confirmatory analysis would not result in helium leakage.

2.6.2 Reduced and Increased External Pressure

Nominal pressure changes, as specified in 10 CFR 71.71(c)(3 and 4) impose stresses of one percent or less of yield on the extremely thick walled BUSS Cask vessel, lid or other loaded components. This level of stress is acceptable.

2.6.3 Vibration

The BUSS Cask closure system and port cover system both utilize highly torqued bolts which preclude loosening due to vibration. Other items such as impact limiter retention systems and cask tiedown systems utilize lock nuts and capture blocks to prevent any loss or loosening due to vibration. These have been reviewed and were found to conform to standard practice which is adequate for this application.

2.6.4 Water Spray

The BUSS Cask packaging consists of closed stainless steel components which were evaluated to not be affected by water spray. There are no areas where water could pool, freeze and do damage. The impact limiters are sealed so that water can not get into the foam space and the foam is closed cell so that water can not penetrate it.

2.6.5 Two Foot Free Drop

The total calculated package weight is 32,900 pounds which requires a normal conditions of transport drop height of two feet. The finite element models used in the BUSS Cask SARP for the normal conditions of transport drop test analysis are the same as the hypothetical accident conditions drop test analysis models. The results presented in the SARP for the normal condition end drop are cask body peak decelerations in the range of 34 g to 54 g, depending on the temperature of the impact limiter foam, and an impact limiter crush depth of 1.4 inches. A confirmatory analysis was performed using a one dimensional model to carry out impact calculations by explicit time iteration. This analysis used a nonlinear material model for the impact limiter foam and an approximation to the actual impact limiter geometry. The results of the analyses give a peak deceleration of 23 g and the same crush depth of 1.4 inches as reported in the SARP. The SARP also reports side and corner drop decelerations of 24 g and 13 g respectively. At these g levels, the resulting stresses in the cask body, lid and bolts are 10% or less of yield. Stresses in all other package components are also acceptable as they are below yield, except that local permanent deformation of the impact limiter structures does take place as expected.

The lid seal maintains helium leak tightness during the normal conditions of transport drop. The lid is held down by twelve 1.5 inch diameter bolts, each of which has a strength of about 200 kips (200,000 pounds). The bolts are tightened to an axial preload level of 45 kips. The SARP recommends a bolt force for helium sealing of 20 kips per bolt based on the manufacturer specification. However, data received from the seal manufacturer by the staff indicates that the seal is maintained as long as the sealing force remains above 5 kips per bolt during unloading. During an end drop, a 54 g acceleration of the lid relative to the cask would correspond to 7 kips per bolt which would not be a significant reduction from the 45 kip preload and the remaining preload is certainly well above the 5 kips needed to maintain the seal.

The possibility of the lid sliding relative to the cask during a normal conditions of transport side drop was addressed in the SARP and checked by confirmatory analysis. For a 24 g relative acceleration, the 1500 pound lid would experience a 36 kip force acting parallel to the plane of the seal ring. The lid is pressed against the cask by 12 lid bolts with a total preload of 540 kips acting through a stainless steel spacer ring in parallel with a metallic "O" ring seal. A review of the seal data provided by the manufacturer, Helicoflex, indicates that the "O" ring seal will react up to 310 kips as the lid is tightened up against the spacer ring. This assures that a force of at least 230 kips will act across the spacer ring. Even with a minimum coefficient of friction and the 230 kips normal force, the 36 kip shear force acting to slide the lid along the body would not cause relative movement. Therefore the bolt preload will maintain the seal during the worst orientation normal condition drop.

2.6.6 Penetration

The impact of a 13 pound rod dropping 40 inches onto the BUSS Cask will not reduce the performance of the exposed components, since the mass of the impacting rod is not significant relative to the massive cask components. The SARP analysis was reviewed and the calculations were verified. It is concluded that the 10 CFR 71 penetration test is not significant for this cask.

2.7 Hypothetical Accident Conditions

2.7.1 Thirty Foot Free Drop

The SARP presents a finite element analysis of the response of the BUSS Cask Packaging to the hypothetical accident conditions 30 foot drop test in lieu of data from actual drop tests. Some of the analytical methods used are supported by results from the tests on similar cask configurations. Comparisons of full size and model test results were made to adequately benchmark the analytical methods used in the SARP. Some of this benchmark data is presented in the SARP.

The end drop analyses presented in the SARP were carried out using an axisymmetric model run through the "Hondo-II" code. The side drop analyses and the corner drop analyses were carried out using the three dimensional models run through the "DYNA-3D" code. The results of these analyses were cask body decelerations of 70 g to 80 g for the end and side drops, and half of that for the corner drop.

Confirmatory analysis of the 30 foot end drop test was performed using the one dimensional model described previously and resulted in a deceleration of 65 g. Total crush depths of 9 inches were obtained as compared to 12 inches determined in the "Hondo-II" finite element analyses presented in the SARP. The confirmatory results are in good agreement with the SARP results. The side drop results were not checked by confirmatory analysis because the end drop g levels are expected to be comparable to the side drop g levels as a result of the homogeneous and isotropic nature of the foam and comparable cross sectional areas.

Loads imposed on the capsules by the basket have been considered by analysis in the SARP. The basket itself experiences minimal deformations and will not collapse. This conclusion is based on elastic analysis for the side drop orientation and on a buckling analysis for the end drop orientation as presented in the SARP. The results show that the capsules do not yield other than locally due to contact stresses at points of contact with the basket and the lid during conditions of transport. The results have been reviewed and found to be acceptable since such local yielding does not impair the ability of the Special Form capsules to maintain containment. The Special Form tests include a percussion test that causes more severe local yielding than the capsules will experience in the cask.

The stresses generated in the cask body for an impact loading corresponding to the computed accelerations, which are all below 100 g, are 2 ksi or lower. The

SARP addresses damage to internal parts, the basket and the Special Form radioactive material capsules, and concludes that component stresses are all well below yield. Analyses are presented for bending, crushing, buckling and other response modes caused by the drop test impact acceleration loadings. The conclusions presented in the SARP have been verified by confirmatory calculations, using statics and beam equations, and stresses were found to be less than 20% of yield. As a consequence of the 30 foot drop, sliding of the lid relative to the cask along the seal ring is a possibility. The SARP does not establish that any gas leakage across the cask lid seal will be prevented but rather takes the position that such leakage will not result in unacceptable conditions. This is discussed further in the Thermal Section. Stress levels in the lid bolts due to these acceleration levels were found to be less than 10% of yield.

2.7.2 Puncture

The SARP presents an analysis of the 40 inch drop of the cask onto a puncture bar using structural models and computer codes similar to those used for the 30 foot drop test. To ensure that the maximum cask decelerations were being generated, the puncture drop simulation was done with a bare cask without impact limiters. Three orientations were modeled: end, side and corner using the "DYNA-2D" code for an axisymmetric end drop model and "DYNA-3D" for three dimensional models of the other two orientations. Decelerations were found to be less than those resulting from the 30 foot drop test and therefore the consequences are acceptable since the 30 foot drop tests were found acceptable. Some local yielding under the puncture bar was predicted by the finite element analyses. This local yielding is acceptable under these hypothetical accident conditions because it does not affect the performance of the cask.

An approximate "quasi-static" confirmatory calculation was carried out applying the maximum force that can be transmitted by the puncture bar as it yields. This analysis shows that deceleration levels of less than 40 g can be expected. Resulting stresses in the lid, bolts, and other components are less than those computed for the 30 foot drop test and are therefore acceptable.

The effect on the seal of the lid striking the puncture bar was reviewed by the staff. The impact force with the puncture bar perpendicular to the lid is less than 500 kips which is the buckling capacity of a bar long enough to reach the lid. This force results in a stress less than 10% of allowable in the lid and cask body. The seal is not affected by this direction of loading. An angular impact results in a much smaller force that depends upon the angle of impact. Sliding of the lid relative to the cask along the seal ring is a possibility. As in the hypothetical accident 30-foot side drop, sliding of the lid relative to the cask along the seal ring is acceptable.

The cask features that may be subjected to an impact with the six inch diameter puncture bar were evaluated, and the SARP shows that each feature is protected. The staff concludes that protection against puncture damage is adequate.

2.7.3 Immersion

The packaging contents are not fissile so 10 CFR 71.73(c)(4) does not apply. The 10 CFR 71.73(c)(5) requirement of 21 psi external pressure, which does apply, has been shown by the staff to result in stresses that are one percent or less of yield in the loaded components and are acceptable.

3. Thermal

3.1 Methods of Analysis and Confirmation

Five geometrical representations and three heat transfer computer codes, presented in the SARP, were used to calculate the thermal performance of the various key packaging components. The temperatures, temperature distributions, and gas pressures have been checked by thermal confirmatory analyses for the maximum 4.0 kW payload, 0.65 to 0.85 million Ci, and have been found to meet 10 CFR 71.

3.2 Normal and Hypothetical Accident Conditions

Four geometrical representations were implemented during confirmatory analyses by both classical calculations using thermal resistances in series, and the General Electric THTB heat transfer computer code. The THTB code has been used and benchmarked by correlating experimental heat transfer data with code results from geometries and thermal conditions similar to those found with packagings. Peak temperatures for the packaging components are listed in Table 1, together with both temperatures from confirmatory analyses performed by the review staff and allowable temperatures. The peak temperatures for normal conditions are based on the cask cavity being filled with helium for heat transfer enhancement. The SARP specifies that the cavity be filled with helium before each shipment. Inadvertent loss of the helium will not jeopardize capsule integrity if the transit and wait period does not exceed 30 days. More than 30 days without helium fill can cause excessive internal corrosion of the cesium chloride capsule cladding. For the hypothetical accident conditions, the peak temperatures are based on the cask cavity being filled with air because the packaging is not required to remain helium leaktight under accident conditions.

In Table 1, the allowable temperatures for the basket, cask body, and cask lid during normal conditions are listed as 800^{O}F, rather than the SARP value of 1475^{O}F, because the structural section uses allowable stresses valid at 800^{O}F but not at 1475^{O}F where ASME Code high temperature design rules would be in effect. The allowable temperatures for the same three components during hypothetical accident conditions are listed as 1100 or 1200^{O}F, instead of the SARP value of 1475^{O}F, because creep rate increases rapidly for the ASME SA-320 bolt insert steel above 1100^{O}F, and for the other materials involved, Type 304 stainless steel and A-286 bolts, above 1200^{O}F. It is permissible for the lid bolt, bolt insert, and threads in the cask body to relax during the hypothetical accident fire since no credit is taken for lid seal performance under hypothetical accident conditions and containment is provided by the Special Form capsules.

Table 1.
Peak and Allowable Packaging Component Temperatures, °F

Component	Normal Conditions Cavity filled with helium: Peak SARP	Peak Staff	Allowable	Hypothetical Accident Conditions Cavity filled with air: Peak SARP	Peak Staff	Allowable
Strontium Fluoride	1189	1196	1475	1387	1392	1475
Cesium Chloride	864	1103	1475	1049	1288	1475
Strontium Fluoride Capsule Inner Wall	1058	1165	1475	1254	1300	1475
Cesium Chloride Capsule Inner Wall	765	819	842	950	1016	1475
Basket	689	745	800	838	948	1200
Cask Body	396	387	800	960	974	1100
Cask Lid	396	429	800	885	942	1200
Cask Seals	396	387	842	Not Applicable		
Limiters	365	429	500	Not Applicable		
Limiters (Avg. Temperature)	None	140	150	Not Applicable		
Personnel Barrier	None	140	180	Not Applicable		

The allowable temperatures for the Special Form capsules are selected to minimize corrosion of the inner containment wall material. For the strontium fluoride Special Form, the allowable temperature of 1475°F is below the eutectic temperature of 1562°F at which accelerated corrosion could occur. For the cesium chloride Special Form, the allowable temperature of 842°F is below the temperature of 876°F at which the corrosion rate could increase to an unacceptable level during normal conditions of transport.

Also in Table 1, allowable temperatures are given for the limiters and personnel barrier while none are given in the SARP. The limiters allowable temperatures are based on accepting 500°F locally to avoid decomposition of the limiter material. At the same time, no more than 150°F average is allowed, to ensure adequate impact properties of the limiter material. The personnel barrier allowable temperature of 180°F is as specified by 10 CFR 71.43(g) for an exclusive use shipment.

For normal conditions of transport including solar insolation, the temperatures calculated by the staff are higher than the SARP values because worst case values were used in confirmatory analyses for such things as the (a) effect of eccentricity on the thermal conductances across gas gaps; (b) thermal conductivity of cesium chloride; and (c) location of the capsules in the cavity.

For both the SARP and worst-case confirmatory analysis temperatures, Table 1 shows the allowable temperatures are not exceeded for any component. During transport conditions, strontium fluoride is entirely compatible with the capsule inner walls for which the allowable temperature is thus well founded. However, the cesium chloride is less compatible with the capsule inner walls for which the allowable temperature warranted further consideration which follows.

The corrosion rate of the capsule inner walls by cesium chloride begins to accelerate at 780°F, somewhat below the allowable temperature, reaching about 1 mil per hour at 1200°F and 10 mils per hour at 1475°F. Even at the higher confirmatory analysis temperature for normal conditions of transport, the capsule inner wall corrosion is estimated to be only about 2 mils, for the 30 day transit and wait period discussed in the SARP. The estimate was made using an equation that relates corrosion rate to temperature. The staff derived the equation by fitting Pacific Northwest Laboratory (PNL) corrosion data with the Arrhenius law. For the minimum wall thickness of 95 mils, 2 mills of corrosion is considered acceptable.

The amount of corrosion calculated for normal conditions of transport is contingent upon helium being retained in the cask cavity during a 30-day transit and wait period. If the helium is replaced by air, the confirmatory calculations show that the capsule inner wall peak temperature is increased from the Table 1 value of 819°F to 980°F, which will increase the inner wall corrosion to about 28 mils in 30 days. This reduction in inner wall thickness is also found acceptable since the Special Form outer wall limits the strain in the inner wall to less than 0.1 for wall thicknesses greater than 50 mills. The strain limit at rupture for Type 316 stainless steel at 980°F is more than 0.3. Another aspect of the cesium chloride capsules is that the chloride experiences volume increases at its phase change temperatures of 876°F and 1193°F.

For hypothetical accident conditions, the capsule inner wall corrosion rate is somewhat higher than for normal conditions but the time of exposure to above normal temperatures is measured in hours instead of days and the total amount of corrosion is found acceptable on that basis.

3.3 Cavity Internal Pressures

Peak cask cavity internal pressures are listed in Table 2, together with both confirmatory analyses and allowable pressures. The pressures were calculated from the cask cavity temperatures using the perfect gas law. Both SARP and confirmatory analyses pressures are lower than the allowable value shown to be acceptable in the SARP structural section.

Table 2.
Peak and Allowable Cask Internal Pressures, psig

Normal Conditions			Hypothetical Accident Conditions		
Peak SARP	Peak Staff	Allowable	Peak SARP	Peak Staff	Allowable
35	36	50	37	38	50

Although not documented in the SARP, the applicant did perform and report steady state thermal testing of a prototype BUSS cask using cesium chloride capsules of known source strengths. As part of the confirmatory thermal evaluation, this work was reviewed. The cask was made of carbon steel. The measured basket and capsule temperatures were as much as 200^{o}F lower than values calculated by methods used for the SARP thermal calculations. These results indicate that the Table 1 calculated peak temperatures are conservative.

4. Containment

4.1 Methods of Analysis and Confirmation

The confirmatory review covered the adequacy of the source description; the adequacy of the containment boundary description, including design and/or performance specifications for the Special Form capsule claddings and welds; and any supportive information or documentation.

The contents are Special Form radioactive cesium chloride or strontium fluoride mixtures that are contained in double walled, all welded capsules. After fabrication, the inner capsules were tested to ensure leak tightness in accordance with ANSI N14.5 or better. The outer capsule closure welds were inspected ultrasonically to ensure weld penetration of at least 55%. The Special Form, double wall capsules provide the containment in this packaging system.

4.2 Normal and Hypothetical Accident Conditions

The SARP has been reviewed to determine that the confinement performance of the package complies with the helium leakage requirements under both normal and hypothetical accident conditions of transport. The scope of the review covered the containment of Special Form radioactive materials, pressurization of the confinement vessel, verifiable confinement criterion, and any supportive information or documentation.

To determine that the Special Form capsules provide adequate containment in packaging, it is sufficient to ensure that the thermal and stress conditions experienced by the Special Form materials in the packaging are less severe than the Special Form test conditions of 10 CFR 71.77. This is true for the BUSS packaging except that the capsules, during normal conditions of transport, are held at an elevated temperature much longer than the 10 minute Special Form elevated temperature test duration but at only 819^{o}F instead of the 1475^{o}F Special Form test condition. The exposure to temperatures less than 1475^{o}F will cause some corrosion of the cesium chloride capsule inner wall. The amount of corrosion, however, is found to be acceptable, being only 2 mils in a 95 mil thick wall as discussed in the Thermal Section.

In addition to the radioactivity double containment provided by the Special Form, double wall capsules, the packaging must also confine helium for heat transfer enhancement. Confirmatory analyses of helium leakage have verified that the helium seal design and seal assembly and leakage testing procedures are adequate for confining helium during the maximum allowable 30 day transit and wait period.

5. Shielding

5.1 Methods of Analysis and Confirmation

The primary shielding in the BUSS Cask is provided by the steel of the body and lid. A maximum of 8.5 x 10^5 Ci of Special Form cesium chloride or strontium fluoride capsules are to be shipped in baskets inside of the cask. The calculations in the SARP are performed assuming a maximum loading of 1.12 x 10^6 Ci to provide a further design margin. Administrative controls in the operating procedures are relied upon to prevent the loading of more than 8.5 x 10^5 Ci. The source terms listed in the SARP are accurately represented.

The principal gamma radiation from the cesium chloride capsules is produced by the decay of the metastable state of ^{137}Ba, which is formed by ^{137}Cs beta decay. The barium emits a 0.662 MeV gamma ray and these gamma rays are considered the total source when performing the cesium calculations. The principal gamma radiation from the strontium fluoride capsules is produced by the decay of ^{90}Zr, which is formed by two successive beta decays starting with ^{90}Sr. The zirconium emits a 1.7 MeV gamma ray but the yield is only 0.02% of the ^{90}Sr. Consequently the worst case for shielding calculations is the maximum cesium chloride loading. There are no neutrons emitted from the decay products of either capsule type and therefore neutron shielding is not required.

5.2 Normal and Hypothetical Accident Conditions

Confirmatory calculations were carried out using MICROSHIELD 2.03 to determine dose rates under normal conditions of transport and under hypothetical accident conditions. The results are summarized in the following table:

Table 3.
RADIATION DOSE RATES, mrem/hr

NORMAL CONDITIONS

	Package Surface			Two meters from Surface		
Position	SARP	Staff	Allowable	SARP	Staff	Allowable
Side	29	76	200	1.1[c]	3	10
Top	64[a]	16[b]	200	2.9[c]	3	10
Bottom	64[a]	16[b]	200	2.9[c]	3	10

HYPOTHETICAL ACCIDENT CONDITIONS

	One Meter From Surface		
Position	SARP	Staff	Allowable
Side	4[d]	11	1000
Top	11[d]	17	1000
Bottom	11[d]	17	1000

[a]At surface of cask lid of body
[b]At surface of impact limiter
[c]At 0.91m from surface
[d]At 1.83m from surface

In the confirmatory analysis, the 0.662 MeV gamma rays from the metastable state decay of ^{137}Ba were considered the radiation source. For normal conditions of transport calculations, 14% of each capsule protrudes above the steel basket and provides an unshielded source. Therefore, 14% of the total 1.12×10^6 Ci of cesium was considered a point source in air located 5.85 cm below the top lid and at the outer ring position of the 16 capsule basket. The remainder of the source was found to contribute less than 6% of the dose rate calculated. The accessible surface of the packaging was taken as being the outside top and bottom surfaces of the impact limiters and the tips of the cooling fins on the sides.

For the hypothetical accident condition, the structural analyses indicates that the capsule basket will not deform but the capsules may protrude out of the basket to touch the top lid. For this condition, 18% of the total 1.12×10^6 Ci of cesium was considered a point source in the air located 4.75 cm below the top lid and at the outer ring position of the 16 capsule basket. Once again the remainder of the source contributes less than 6% of the dose rates calculated. In this case, the accessible surface was the outside top lid and the bottom of the body.

Since the dose rates at the bottom surface will be less than at the top, the dose rates at the bottom were not calculated but are listed as the same value as the top.

The evaluation of the shielding performance demonstrates that under normal and hypothetical accident conditions of transport, the transportation of Special Form capsules is in accordance with 10 CFR 71.

6. Criticality

Since the allowable contents are non-fissile materials, criticality is not a concern.

7. Operating Procedures

The operating procedures presented in the SARP will result in safe operations of the BUSS cask when incorporated into the user specific procedures. Procedures are included which assure that the thermal and radioactive loading of the cask will not exceed design limits, and multiple opportunities are present to detect contents overloads. Appropriate radiological protection is assured through the use of timely radiation surveys during both loading and unloading operations.

Review of the physical condition of the packaging and its critical seal surfaces is required prior to each usage. Post-loading leak tests will assure the integrity of the seals prior to shipment. Closure of the cask lid is done in a straightforward manner as is the assembly of the impact limiters onto the cask body and the loading of the assembled cask onto the shipping cradle and is considered acceptable.

As a final protection against contents overloading, the temperature of the cask body surface is monitored for a specified time period after cask closure to insure conformance with predicted values.

A review of the operating procedures found that they were acceptable and in conformance with established guidelines and criteria provided in the Operating Procedures Section of the DOE Packaging Review Guide. The evaluation of the operating procedures provides assurance that under normal and hypothetical accident conditions of transport the transportation of Special Form capsules is in accordance with 10 CFR 71.

8. Acceptance Tests and Maintenance Program

Fabrication of the parts of the BUSS cask to the required criteria is assured by the application of numerous inspection tests and material verifications. Forging integrity is verified through magnetic and liquid penetrant inspection as well as radiographic and/or ultrasonic techniques. Dimensional checks are indicated in a standard, approved manner. Fabrication of the foam-filled impact limiters is verified by weight/volume measurements before and after filling and by testing of a box sample of the foam batch.

To verify the structural design criteria, a hydrostatic pressure test is required before first use that verifies a 150% pressure capability of the cask body and lid. In addition, helium leak tests are required both prior to first use and periodically thereafter.

Shielding integrity is verified before first use by loading the actual payload and making radiation measurements at the surface and at 2 meters distance. Thermal testing before first use is also required and is performed with the actual payload, verifying surface temperatures within design predictions. It should be noted that should shielding or thermal tests exceed the acceptance levels for a particular cask, the acceptable loading for that cask will be reduced to levels that will result in proper thermal and radiological criteria.

After each use, inspection for "wear and tear" and the usual cleaning of components is performed. Regular maintenance requires the BUSS cask lid and port seals to be replaced after each shipment. A periodic test and inspection schedule is provided to assure that the cask body, impact limiters, trunnions, and other components meet original requirements over the life of the packaging.

9. Quality Assurance

The Quality Assurance (QA) Plan presented in the SARP has been reviewed and found to meet the requirements of 10 CFR 71, Subpart H. The QA plan provides sufficient control over all items and quality-affecting activities that are important-to-safety as applied to the design, fabrication, assembly, testing, operations, and maintenance activities of the BUSS cask. The BUSS QA Plan is based on a graded approach for QA requirements as described in 10 CFR 71.101. The graded approach in the QA Plan includes for each item and quality-affecting activity an important-to-safety list (Q-list) that is based on the design function of the item relative to the safety and performance requirements for the complete shipping cask. The Q-list is based on three QA levels with associated definitions for each. The QA level of each important-to-safety item is based on the following criteria and, the necessary level of QA requirements is invoked for each item. In addition, the QA Plan requires the user to invoke the same level of QA requirements for any maintenance or repair as the original shipping cask had invoked.

1. QA Level 1 (Critical) items whose failure or malfunction will directly result in an unacceptable condition of shielding.

2. QA Level 2 (Major) items whose failure or malfunction could indirectly result in an unacceptable condition of shielding.

3. QA Level 3 (Minor) items whose failure or malfunction will not reduce the packaging effectiveness and will not result in an unacceptable condition of shielding.

After determining the applicable QA level for each important-to-safety item, the appropriate level of QA effort for the design, fabrication, assembly, testing, acceptance, operations, and maintenance activities was determined from the 18 QA elements identified in 10 CFR 71, Subpart H and ASME/ANSI NQA-1. The 18 elements identified in the SARP are organization; quality assurance program; design control; procurement document control; instructions, procedures, and drawings; document control; control of purchased material, parts, and components; identification and control of materials, parts and components; control of special processes; inspection control; test control; control of measuring and test equipment; control of handling, shipping, and storage; control of inspection, test and operating status; control of nonconforming materials, parts, or components; corrective action; QA records; and QA audits.

Basis for acceptance of the QA Plan has been conformance with established criteria in Subpart H of 10 CFR Part 71. The QA Plan in the SARP provides assurance that the BUSS cask is designed, fabricated, tested, accepted, and used in accordance with federal regulations.

Approved by
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